63-1-2

A CASE HISTORY INVESTIGATION OF WINTER STORMS WHICH PRODUCE SUSTAINED SURFACE WIND SPEEDS 50 KNOTS OR GREATER AT TEXAS TOWER 2 AND TEXAS TOWER 3

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September 1962

A. INTRODUCTION.

1. Texas Tower 2 is on Georges Bank approximately 110 miles east of Chatham, Massachusetts. Texas Tower 3 is on Nantucket Shoals approximately 35 miles southeast of Nantucket Island. Both of these towers are in an area which is periodically subject to hurricanes or tropical storms during the summer months and to extratropical storms during the winter months October through April. Because of the high wind and sea conditions caused by these storms, the Air Force established criteria (1) for evacuating both towers before the onset of the high wind and sea regimes. Although designed to withstand winds of 108 knots and 35 foot breaking waves, the possibility of rare waves of extreme height dictated the establishment of evacuation criteria considerably lower than the design criteria. On 20 October 1961, Headquarters, United States Air Force established an evacuation criterion of 50 knots sustained wind. On 7 November 1961, Headquarters, Air Defense Command established a 35-foot significant wave forecast as a criterion for evacuation. The 53d Weather Reconnaissance Squadron provides the tropical cyclone information through the Air Force Hurricane Advisory Bulletins; the U.S. Navy Fleet Weather Central at Suitland provides the wave forecasts; and 4th Weather Wing forecasters must provide the wind forecasts during the winter months as specified in the 4th Weather Wing Operations Plan (2).

2. The winter storms present a very difficult forecast problem. The majority of winter storms which produce sustained winds 50 knots or greater are intense cyclones with storm tracks within 300 nautical miles of the towers. Many cyclones traverse the tower area during the winter months, but only about 10%-20% of these storms produce high sustained wind speeds at either tower. A larger percentage of storms

contain wind speeds $\geqslant$ 50 knots, but these high wind speeds may only be reported in other quadrants of the storm and not necessarily occur at the specific tower sites. Meteorologically, the storm may verify as a 50-knot storm, but cannot be verified operationally as a Texas Tower storm occurrence. The forecast problem is three-fold, requiring a high degree of accuracy in forecasting the storm track, storm intensity and timing the rate of development.

3. This investigation employs the case study approach (3) to all winter storms which have produced high wind speeds at either tower. The purpose of this study is to:

a. Analyze and summarize the characteristics of winter storm systems which produce sustained winds of 50 knots or greater at either Texas Tower 2 or Texas Tower 3.

b. To establish sufficient criteria which will permit identification of these storm systems with sufficient lead time for evacuation operations.

B. EVACUATION PROCEDURES.

1. Specified evacuation procedures involve a complicated array of resources, capabilities, limitations and alternative tactics (1, pp 6-13; 2, Annex Bravo). Since the beginning of this investigation there have been many changes in the operational aspects of the problem and even at the time of this report consideration is being given to new evacuation resources and procedures. Therefore some of the work and results reported upon may not be pertinent to the problem as it stands at the time of reading, but are included for what value they might have.

2. Because of the proximity of the towers, they are usually affected

by the same weather regimes. Evacuation operations begin at both towers on the basis of a forecast of wind speeds $\geqslant$50 knots or significant wave heights $\geqslant$35 feet.

3. In recent efforts to improve the weather support procedures, 4th Weather Wing Scientific Services personnel have assumed the following:

a. The primary forecast problem is to identify those storms which produce sustained winds $\gtrsim$50 knots.

b. HSS-2 helicopters will be the primary mode for evacuation of both towers.

c. When a favorable evacuation period exists at the towers, conditions are also favorable at Otis AFB or at suitable alternates (4).

C. OPERATIONAL WEATHER AND TIME LIMITS.

1. Weather minimums for HSS-2 operation are as follows (1, pp 10-11; 2, p B-2):

a. Ceiling and visibility: 700 feet and one mile (may later be lowered) both day and night for landing at the towers; 200 feet and $\frac{1}{2}$ mile for take-off from the towers and landing at Otis AFB; GCA minimums at alternate recovery bases.

b. Maximum wind speed (gust value) for take-off and landing: 50 knots.

2. An HSS-2 can reach Tower 2 in one hour, load 21 passengers in five minutes and transport them to the mainland in one hour. It can reach Tower 3 in 30 minutes, load 21 passengers in five minutes and transport them to the mainland in 30 minutes. With at least four HSS-2's in commission (assumption B3b) the evacuation of Tower 2 takes three

hours while that of Tower 3 takes two hours.

3. The issuance of a forecast of wind speeds $\geq$50 knots must be early enough to allow completion of evacuation operations. The forecast deadline is not simply a time of day or even a stage of storm development. The forecaster must, as he works with each individual storm threat, appraise the various meteorological factors that determine when favorable evacuation conditions exist. Thus the precise statement of the problem cannot specify a fixed time for issuing the forecast. The statement is also unusual in that it must cope with the coupling of two weather events; i.e., 50-knot wind speed at either tower and a prior suitable evacuation period for the operational area.

D. PRECISE STATEMENT OF THE FORECAST PROBLEM.

With the operational weather and time limits established, the forecast problem is: During the winter period of October through April, to forecast prior to a favorable evacuation period during which the ceiling and visibility at both towers are continuously $\geq$700 feet and $\geq$ 1 mile, and there are no wind speeds (including gusts) $\geq$50 knots, the occurrence or nonoccurrence of sustained wind speeds $\geq$50 knots at either of the Texas Towers.

E. TYPES AND PERIODS OF DATA COLLECTED.

1. 4th Weather Wing Scientific Services personnel collected and used the following data in this study. Except for the manuscript charts and microfilm records used on a loan basis, these data are on file for future use.

a. Microfilm WBAN 10A records:

Texas Tower 2	Texas Tower 3
1956-Nov, Dec	1956-(tower not operational)
1957-Jan thru Apr, Oct thru Dec	1957-Nov, Dec
1958-Jan thru Apr, Oct thru Dec	1958-Jan thru Apr, Oct thru Dec
1959-Jan thru Apr, Oct thru Dec	1959-Jan thru Apr, Oct thru Dec
1960-Jan thru Apr, Oct thru Dec	1960-Jan thru Apr, Oct thru Dec
1961-Jan thru Apr	1961-Jan thru Apr

b. Six-hourly surface charts and 12-hourly 850 mb and 500 mb charts covering North America (loaned by Denver regional office of U.S Weather Bureau); microfilm surface, 850 mb, 700 mb, 500 mb, 300 mb, 250 mb and 200 mb charts (loaned by United Air Lines' Office of Meteorology); for the periods specified above. Now on file are microfilm NMC analyses of all surface and constant pressure charts from October 1956 through June 1961.

c. Photostatic copies of the WBAN 10A records of the following stations, covering for each Texas Tower storm the 48-hour period centered on the time of the first sustained wind $\geq$50 knots: Otis AFB, Massachusetts; Nantucket, Massachusetts; Hanscom AFB, Massachusetts; Westover AFB, Massachusetts; Quonset Point, Rhode Island; Langley AFB, Virginia; McGuire AFB, New Jersey; Andrews AFB, D.C., Olmstead AFB, Pennsylvania; Griffiss AFB, New York; and Dow AFB, Maine.

F. UPPER AIR CHARACTERISTICS OF WINTER STORMS.

1. Winter storms which cause high wind regimes at the tower sites are those which move into the tower area from the southwest quadrant (5). These storms develop rapidly in the eastern United States and are beneath southwesterly flow aloft. We found that the behavior of these

storms is similar to those previously studied by Shafer and Funke (6), (7), and others (8). We postulated that certain upper-air predictors used in these studies, particularly those related to cyclone development, could be used to isolate the significant features of the upper-air patterns which would distinguish those storms which produced wind speeds ≥ 50 knots at the towers, from those storms associated with lighter winds.

2. The following upper-air parameters were computed from each upper-air chart during the entire history of the surface low.

a. 500 mb trough sharpness. This parameter is proportional to the cyclonic circulation across the trough line at the latitude of the surface low.

b. 500 mb temperature factor. A parameter which describes the phase relationship of the 500 mb wind field and thermal trough, and to a certain extent, the strength of the temperature field at 500 mb.

c. 500 mb maximum temperature gradient. This parameter is a measure of the broad steep gradient of temperature to the northwest of the surface low, which experience has shown is a prime requisite for rapid development of surface lows.

d. 500 mb trough distance. This parameter is a measure of the proximity of the upper trough to the surface low.

e. 500 mb height difference. This parameter is a measure of the space-mean wind velocity over the surface low.

f. 850 mb temperature factor. A parameter which describes the low-level phase relationship of the 850 mb wind field and thermal trough.

g. 850 mb advective factor. A parameter which describes the low-level temperature advection field.

3. For each Texas Tower storm occurrence, we analyzed the parameters at the time the surface wind speeds first reached ≥50 knots at either tower, and at various time intervals prior to the occurrence of wind speeds ≥50 knots. We found large variations between individual storms and were unable to isolate a set of restrictive values common to all storms. We also found that these values did not satisfactorily screen the occurrence storms from nonoccurrence storms (i.e., the negative check failed). It should be noted that we made no attempt to evaluate the "Category IV Cyclone" objective method (6, 7), which provides a 30-hour forecast of the position and intensity of cyclones. We attempted to use the parameters as screening devices in our case study approach to identify storms which produce ≥50-knot wind speeds at either tower. We do not imply that upper-air parameters are unimportant. On the contrary, they are certainly useful in predicting cyclone development and are, as a matter of fact, considered routinely by the National Meteorological Center (NMC) in the preparation of surface prognostic charts (9). The forecast problem requires a critical prognosis of the storm track, storm intensity and timing of the rate of development. Upper-air charts received at 12-hour intervals may not provide sufficient detail when used as a separate screening device. It appears that the best approach to the problem is to:

a. Make maximum utilization of the NMC surface prognostic charts since these products will have incorporated significant upper-air trends and developments (9, 10).

b. Make maximum utilization of the latest hourly surface data in the appraisal and modification of the predicted storm systems (11).

G. SURFACE DATA CHARACTERISTICS OF WINTER STORMS.

1. Wind Characteristics. We found 38 storms which produced sustained wind speeds ≥50 knots at either or both towers. Texas Tower 2 experienced 30 storms during the five winter seasons (1956-61) and Texas Tower 3 experienced 24 storms during the four winter seasons (1957-61). Sixteen of the Texas Tower 3 storms were common with Texas Tower 2 storms. Table 1 is the master log of all Texas Tower storms which lists the dates and times (Z) of various threshold values of wind speed, and maximum wind velocities attained during each storm. From Table 1, we may ascertain a variety of pertinent wind characteristics. Some of the pertinent characteristics are summarized below.

a. Wind characteristics at individual towers.

(1) Texas Tower 2.

(a) Hours between first gust ≥50 knots and the first sustained wind ≥50 knots (30 cases):

Minimum	< 1 hrs	53% of cases	≤ 1 hr
Mean	2.5 hrs	90% of cases	≤ 6 hrs
Maximum	11 hrs		

(b) Hours between first sustained wind ≥50 knots and last sustained wind ≥50 knots (30 cases):

Minimum	< 1 hrs	33% of cases	≤ 1 hr
Mean	7.5 hrs	53% of cases	≤ 3 hrs
Maximum	35 hrs	90% of cases	≤ 18 hrs

(c) Hours between first gust ≥50 knots and last gust ≥50 knots (37 cases):

Minimum	< 1 hrs	8% of cases	≤ 1 hrs
Mean	14.6 hrs	51% of cases	≤ 11 hrs
Maximum	56 hrs	89% of cases	≤ 29 hrs

(2) Texas Tower 3.

(a) Hours between first gust ≥50 knots and the first sustained wind ≥50 knots (24 cases):

Minimum	< 1 hrs	38% of cases	≤ 1 hrs
Mean	4.0 hrs	88% of cases	≤ 6 hrs
Maximum	33 hrs		

(b) Hours between first sustained wind ≥50 knots and last sustained wind ≥50 knots (24 cases):

Minimum	< 1 hrs	50% of cases	≤ 1 hrs
Mean	6.6 hrs	92% of cases	≤ 18 hrs
Maximum	26 hrs		

(c) Hours between first gust ≥50 knots and last gust ≥50 knots (28 cases):

Minimum	< 1 hrs	10% of cases	≤ 1 hrs
Mean	12.1 hrs	50% of cases	≤ 6 hrs
Maximum	37 hrs	93% of cases	≤ 29 hrs

(3) The above summaries show large ranges in the elapsed times for each category, therefore the mean values are nonrepresentative. The frequency distributions however show certain similarities. In particular, the 90% frequency level for the group of Texas Tower 2 cases is almost identical to the 90% level for the group of Texas Tower 3 cases (i.e., ≤6 hours from first gust to first sustained; sustained duration ≤18 hours; gust duration ≤29 hours). Note that these are individual characteristics for each tower derived separately from each group

TABLE 1. Log of winter storms which caused winds ≥50 knots at the Texas Towers; times of gust and sustained winds ≥50 knots; and maximum winds reported. (NR: Not reported; NO: Not operational)

Case No	Month and Year	Beginning Times Gust ≥50 TT 2	Beginning Times Gust ≥50 TT 3	Beginning Times Sust ≥50 TT 2	Beginning Times Sust ≥50 TT 3	Ending Times Sust ≥50 TT 2	Ending Times Sust ≥50 TT 3	Ending Times Gust ≥50 TT 2	Ending Times Gust ≥50 TT 3	Hours Duration Gust/Sustained TT 2	Hours Duration Gust/Sustained TT 3	Maximum Wind Velocity Direction-Speed/Time-Date TT 2	Maximum Wind Velocity Direction-Speed/Time-Date TT 3
1	Dec 57	11Z:01	14Z:01	NR	14Z:01	NR	15Z:01	05Z:03	17Z:01	42/NR	3/<1	W46+54/01Z:03	W58+63/15Z:01
2	Dec 57	19Z:04	19Z:04	01Z:05	00Z:05	19Z:05	18Z:05	00Z:06	21Z:05	29/18	26/18	NE60+80/10Z:05	NE60+78/06Z:05
3	Jan 58	06Z:08	04Z:08	07Z:08	06Z:08	10Z:08	08Z:08	12Z:08	08Z:08	2/3	4/2	WNW53+59/06Z:08	S60+83/07Z:08
4	Jan 58	06Z:15	06Z:15	12Z:15	07Z:15	12Z:15	07Z:15	13Z:15	08Z:15	7/<1	2/<1	NE50+56/12Z:15	E53+61/07Z:15
5	Jan 58	06Z:23	03Z:23	NR	03Z:23	NR	03Z:23	06Z:23	05Z:23	<1/NR	2/<1	WNW46 /18Z:23	SW50+55/03Z:23
6	Feb 58	09Z:09	10Z:09	NR	12Z:09	NR	12Z:09	09Z:09	12Z:09	<1/NR	2/<1	SW44+53/09Z:09	W50+56/12Z:09
7	Feb 58	12Z:16	08Z:16	15Z:16	21Z:16	04Z:17	00Z:17	06Z:17	04Z:17	18/13	7/3	NE54+64/15Z:16	SW57+65/22Z:16
8	Mar 58	20Z:14	17Z:14	22Z:14	20Z:14	22Z:14	20Z:14	04Z:15	21Z:14	8/<1	4/<1	E50+62/22Z:14	E52+60/20Z:14
9	Mar 58	18Z:20	15Z:20	22Z:20	17Z:20	03Z:21	03Z:21	06Z:21	04Z:21	12/5	13/10	NNE52+63/20Z:20	E60+68/21Z:20
10	Apr 58	15Z:01	14Z:01	17Z:01	17Z:01	20Z:02	06Z:02	02Z:03	17Z:02	11/27	27/13	NE53+65/00Z:02	NNE59+80/20Z:01
11	Nov 58	10Z:30	07Z:30	NR	07Z:30	NR	12Z:30	19Z:30	16Z:30	9/NR	9/5	WNW48+57/17Z:30	W50+58/07Z:30
12	Jan 59	11Z:05	04Z:05	13Z:05	07Z:05	00Z:07	08Z:06	19Z:07	09Z:06	56/35	29/25	W55+69/23Z:05	W57+66/07Z:06
13	Mar 59	16Z:12	15Z:12	18Z:12	17Z:12	00Z:14	18Z:12	11Z:14	03Z:14	43/30	36/1	E55+65/18Z:12	E51+57/17Z:12
14	Oct 59	02Z:19	02Z:19	NR	02Z:19	NR	02Z:19	03Z:19	03Z:19	1/NR	1/<1	NW44 /05Z:19	WNW53+67/02Z:19
15	Dec 59	13Z:22	11Z:22	13Z:22	12Z:22	19Z:22	12Z:22	01Z:23	16Z:22	12/6	5/<1	NE56 /16Z:22	NE50+57/12Z:22
16	Jan 60	10Z:09	06Z:09	NR	09Z:09	NR	09Z:09	18Z:09	12Z:09	8/NR	6/<1	NW47+55/13Z:09	WNW51+64/09Z:09
17	Jan 60	08Z:16	07Z:16	11Z:16	13Z:16	12Z:16	13Z:16	23Z:17	20Z:17	39/1	37/<1	WNW51 /11Z:16	WSW53+64/13Z:16
18	Feb 60	13Z:14	11Z:14	15Z:14	20Z:15	18Z:14	20Z:15	18Z:14	20Z:15	5/3	21/<1	ESE56+62/17Z:14	W51+60/20Z:15

Table 1 Continued

Case No	Month and Year	Beginning Times				Ending Times				Hours Duration Gust/Sustained		Maximum Wind Velocity Direction-Speed/Time-Date	
		Gust ≥50		Sust ≥50		Sust ≥50		Gust ≥50					
		TT 2	TT 3	TT 2	TT 3	TT 2	TT 3	TT 2	TT 3	TT 2	TT 3	TT 2	TT 3
19	Mar 60	01Z:04	00Z:04	09Z:04	06Z:04	01Z:05	17Z:04	02Z:05	01Z:05	25/16	25/11	ENE62+74/15Z:04	NE55+65/16Z:04
20	Dec 60	NR	NR	NR	00Z:09	NR	03Z:09	NR	NR	NR/NR	3/3	NW38+42/00Z:09	W53 /01Z:09
21	Dec 60	08Z:12	NR	08Z:12	05Z:12	02Z:13	07Z:13	09Z:13	03Z:14	25/18	46/26	ENE72+81/13Z:12	ENE80+90/13Z:12
22	Jan 61	20Z:01	21Z:01	NR	06Z:02	NR	06Z:02	11Z:02	07Z:02	15/NR	10/<1	W48+62/09Z:02	W50 /06Z:02
23	Jan 61	13Z:20	05Z:20	15Z:20	06Z:20	00Z:21	21Z:20	01Z:21	04Z:21	12/11	23/15	NW58+70/23Z:20	NW66+80/20Z:20
24	Feb 61	13Z:04	09Z:04	14Z:04	11Z:04	05Z:05	04Z:05	11Z:05	07Z:05	25/15	22/17	ENE78+84/00Z:05	E65+80/15Z:04
25	Dec 56	19Z:18	NO	19Z:18	NO	19Z:18	NO	21Z:18	NO	2/<1	NO	W50+57/19Z:18	NO
26	Dec 56	04Z:30	NO	04Z:30	NO	08Z:30	NO	03Z:31	NO	23/4	NO	SW69+84/05Z:30	NO
27	Jan 57	06Z:08	NO	06Z:08	NO	10Z:08	NO	12Z:08	NO	6/4	NO	NNW53+59/06Z:08	NO
28	Jan 57	22Z:10	NO	23Z:10	NO	01Z:11	NO	04Z:11	NO	6/2	NO	N52+64/23Z:10	NO
29	Mar 57	10Z:20	NO	19Z:20	NO	20Z:20	NO	01Z:21	NO	15/1	NO	NNE52+63/20Z:20	NO
30	Feb 58	04Z:02	07Z:02	05Z:02	NR	05Z:02	NR	10Z:02	07Z:02	6/<1	<1/NR	N56+68/05Z:02	N40+51/07Z:02
31	Feb 58	14Z:28	09Z:28	15Z:28	NR	15Z:28	NR	18Z:28	13Z:28	4/<1	4/NR	E53+62/15Z:28	E48+53/09Z:28
32	Dec 58	23Z:30	NR	10Z:31	NR	11Z:31	NR	13Z:31	NR	14/1	NR/NR	N50+63/10Z:31	N35+42/09Z:31
33	Mar 59	17Z:04	15Z:04	17Z:04	NR	17Z:04	NR	19Z:04	15Z:04	2/<1	<1/NR	WSW50+64/17Z:04	WSW43+51/15Z:04
34	Mar 59	23Z:27	00Z:28	04Z:28	NR	13Z:28	NR	02Z:29	06Z:28	27/9	6/NR	NE58+68/06Z:28	ENE47+56/03Z:28
35	Mar 61	09Z:09	01Z:09	10Z:09	NR	11Z:09	NR	12Z:09	09Z:09	3/1	8/NR	E51+62/11Z:09	E45+60/09Z:09
36	Mar 61	17Z:14	NR	18Z:14	NR	21Z:14	NR	21Z:14	NR	4/3	NR/NR	E53+60/19Z:14	E30+38/16Z:14
37	Mar 61	03Z:26	NR	04Z:26	NR	06Z:26	NR	12Z:26	NR	9/2	NR/NR	NW50 /04Z:26	NW35 /13Z:26
38	Apr 61	01Z:30	05Z:30	02Z:30	NR	05Z:30	NR	14Z:30	11Z:30	13/3	6/NR	NNE52+65/04Z:30	NW45+55/08Z:30

of Texas Tower 2 and Texas Tower 3 cases. Each group does not contain the same cases (see Table 2). For example, in the sustained wind duration category above, the group of 30 cases for Texas Tower 2 is different than the group of 24 cases for Texas Tower 3. The 90% level will probably vary when computed for a group of cases common to both towers. To illustrate this point, we did compute the 90% level for the sustained wind duration category for the special group of cases common to both towers (i.e., 16 storms which caused sustained winds ≥50 knots at both towers) and found that the 90% level was indeed different, especially for Texas Tower 2.

Texas Tower 2: 90% of cases ≤27 hours

Texas Tower 3: 90% of cases ≤19 hours

b. Lag between beginning times of wind occurrences at Texas Tower 2 and Texas Tower 3. Table 2, constructed from Table 1, shows occurrences of sustained winds and gusts ≥50 knots, which tower had the earliest occurrences, and the elapsed time between the Texas Tower 2 and Texas Tower 3 occurrences.

(1) For those storms (16 cases) which produced sustained winds ≥50 knots at both towers, Texas Tower 3 experienced the sustained winds at the same time or earlier in 81% (13/16) of the cases. Of these, the average was 3.0 hours earlier. Texas Tower 3 always experienced the first gust ≥50 knots as early or earlier than Texas Tower 2. The first gust occurred an average of 2.6 hours earlier at Texas Tower 3. It is interesting to note that even in the three cases where Texas Tower 2 experienced the sustained winds first, Texas Tower 3 still experienced the first gust.

Table 2

Time Differences Between Tower's First Sustained Winds and Gusts ≥ 50 Knots.

Case	Reported Sustained Wind Occurrence		Reported Gust Occurrence		Time Differences in Hours between Towers (Positive Sign Means TT 3 Earlier)	
	TT 2	TT 3	TT 2	TT 3	First Sustained	First Gust
1		X	X	X		-3
2	X	X	X	X	+1	0
3	X	X	X	X	+1	+2
4	X	X	X	X	+5	0
5		X	X	X		+3
6		X	X	X		-1
7	X	X	X	X	-6	+4
8	X	X	X	X	+2	+3
9	X	X	X	X	+5	+3
10	X	X	X	X	0	+1
11		X	X	X		+3
12	X	X	X	X	+6	+7
13	X	X	X	X	+1	+1
14		X	X	X		0
15	X	X	X	X	+1	+2
16		X	X	X		+4
17	X	X	X	X	-2	+1
18	X	X	X	X	-29	+2
19	X	X	X	X	+3	+1
20		X				
21	X	X	X		+3	

Table 2 Continued:-

Case	TT 2	TT 3	TT 2	TT 3	First Sustained	First Gust
22		X	X	X		-1
23	X	X	X	X	+7	+8
24	X	X	X	X	+3	+4
25	X	NO	X	NO	NO	NO
26	X	NO	X	NO	NO	NO
27	X	NO	X	NO	NO	NO
28	X	NO	X	NO	NO	NO
29	X	NO	X	NO	NO	NO
30	X		X	X		-3
31	X		X	X		+5
32	X		X			
33	X		X	X		+2
34	X		X	X		-1
35	X		X	X		+8
36	X		X			
37	X		X			
38	X		X	X		-4
TOTAL CASES	30	24	37	28	16	28

(2) For those storms (38 cases) which produced sustained winds $\geq$50 knots at either or both towers, 28 of these offer a comparison for earliest gust occurrences. Of these, Texas Tower 3 experienced the first gust $\geq$50 knots at the same time or earlier than Texas Tower 2 in 79% (22/28) of the cases. The average was 2.9 hours earlier.

c. Nature of the wind data. We consider the wind data in this study as a limited sample of the total population of the wind speeds for the five years of record. First, the Manual of Surface Observations (12) specifically instructs observers not to take average wind speed observations during periods of extreme wind speeds (either high or low). Secondly, the observers record only one wind speed value each hour. We were therefore unable to determine the number of systems that produced sustained winds of at least 50 knots between regular hourly observations during the 1956-1961 winter seasons.

2. Storm Characteristics at the Time Sustained Wind Speeds First Reach $\geq$50 knots.

a. Except for a special type of storm which will be discussed later (e.g., cases 11, 14, 16, 20, 25), all storms were centered within a pear-shaped area off New England and Nova Scotia as shown in Figure 1. Furthermore, 97% (32/33) of these storms enter this storm occurrence area through a very limited part of its boundary, shown as a double stroke line A-B in Figure 1. One storm (case 12), entered the occurrence area through B-C.

b. Approximately 55% (18/33) of the storms produced the first sustained wind $\geq$50 knots as they approached the towers from the southwest and 45% (15/33) of the storms produced the first sustained wind $\geq$50 knots

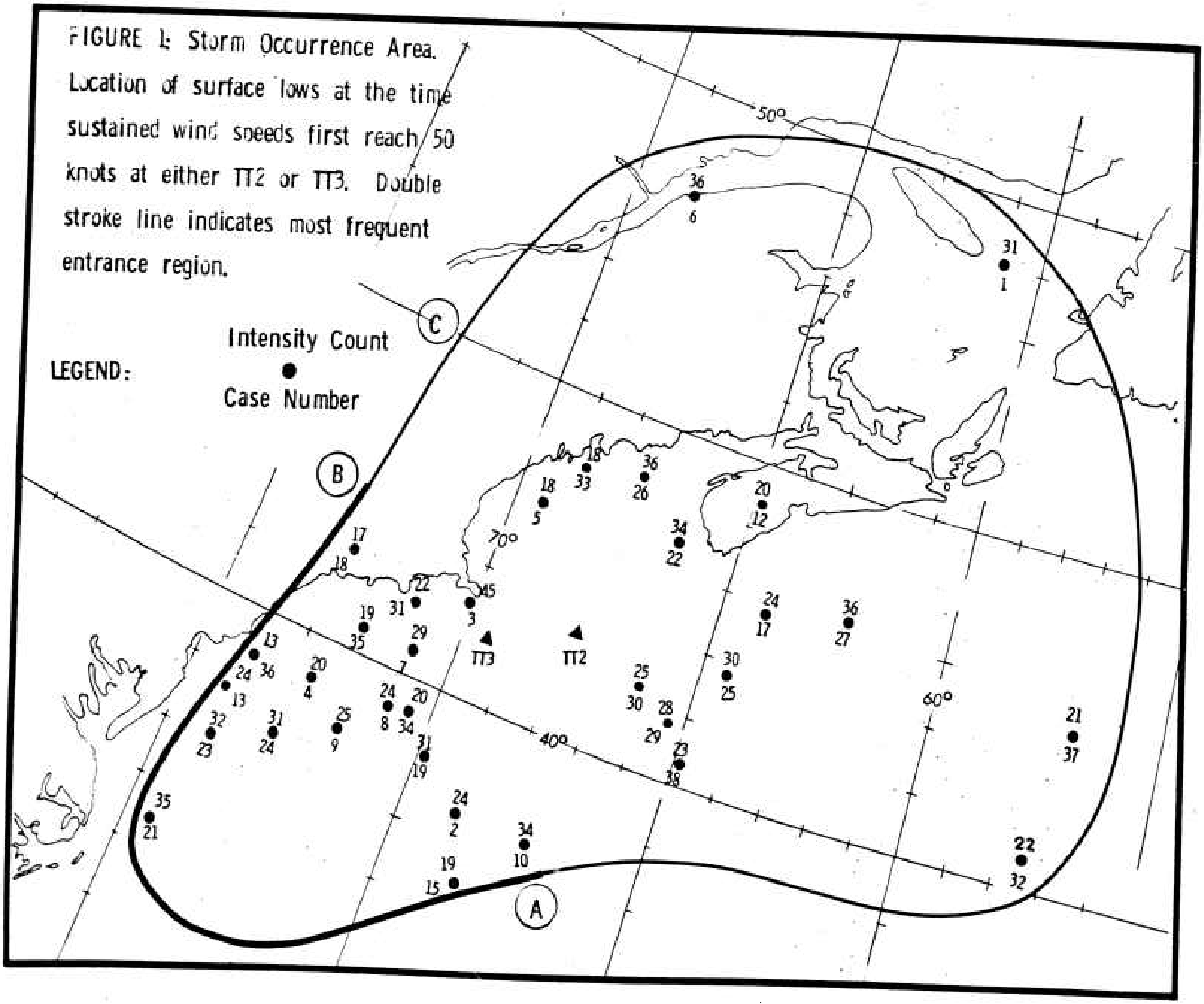


FIGURE 1: Storm Occurrence Area. Location of surface lows at the time sustained wind speeds first reach 50 knots at either TT2 or TT3. Double stroke line indicates most frequent entrance region.

as they moved beyond the towers.

c. Figure 1 shows the intensity count* of the storm systems at the time of the first sustained wind ≥50 knots. These values ranged from 13 mb to 45 mb with an average of 26 mb for all storms. There is no significant difference between those storms that produced sustained winds ≥50 knots as they approached or moved beyond the towers.

3. Storm Intensity.

a. We computed the intensity count of each storm at six-hourly intervals from the time the surface low first originated until the storm moved out of the tower area. Investigations were made to isolate the intensity count characteristics at the time of the first sustained wind ≥50 knots, and at various times prior to the occurrence of winds ≥50 knots. We were unable to isolate any restrictive values of intensity count at these times which would satisfactorily screen the occurrence storms from nonoccurrence storms.

b. Except for the five FROPA (frontal passage) storms mentioned earlier, we found a significant storm characteristic which was both a necessary and sufficient criterion. We found that all storms (33 cases) which produced sustained winds ≥50 knots reached an intensity count of at least 19 mb at some time during their track through the circular area shown in Figure 2. Apparently storms which produce wind speeds ≥50 knots must attain this minimum degree of intensity in the immediate vicinity of

*The intensity count is an objective measure of the strength of the cyclonic circulation or pressure gradient around the low. This objective measurement has been successfully employed by J.J. George (6) and others in cyclogenesis studies. It is defined as the average of the maximum increases in sea level pressure from the storm center to 8.7 degrees of latitude out in each of the four cardinal directions.

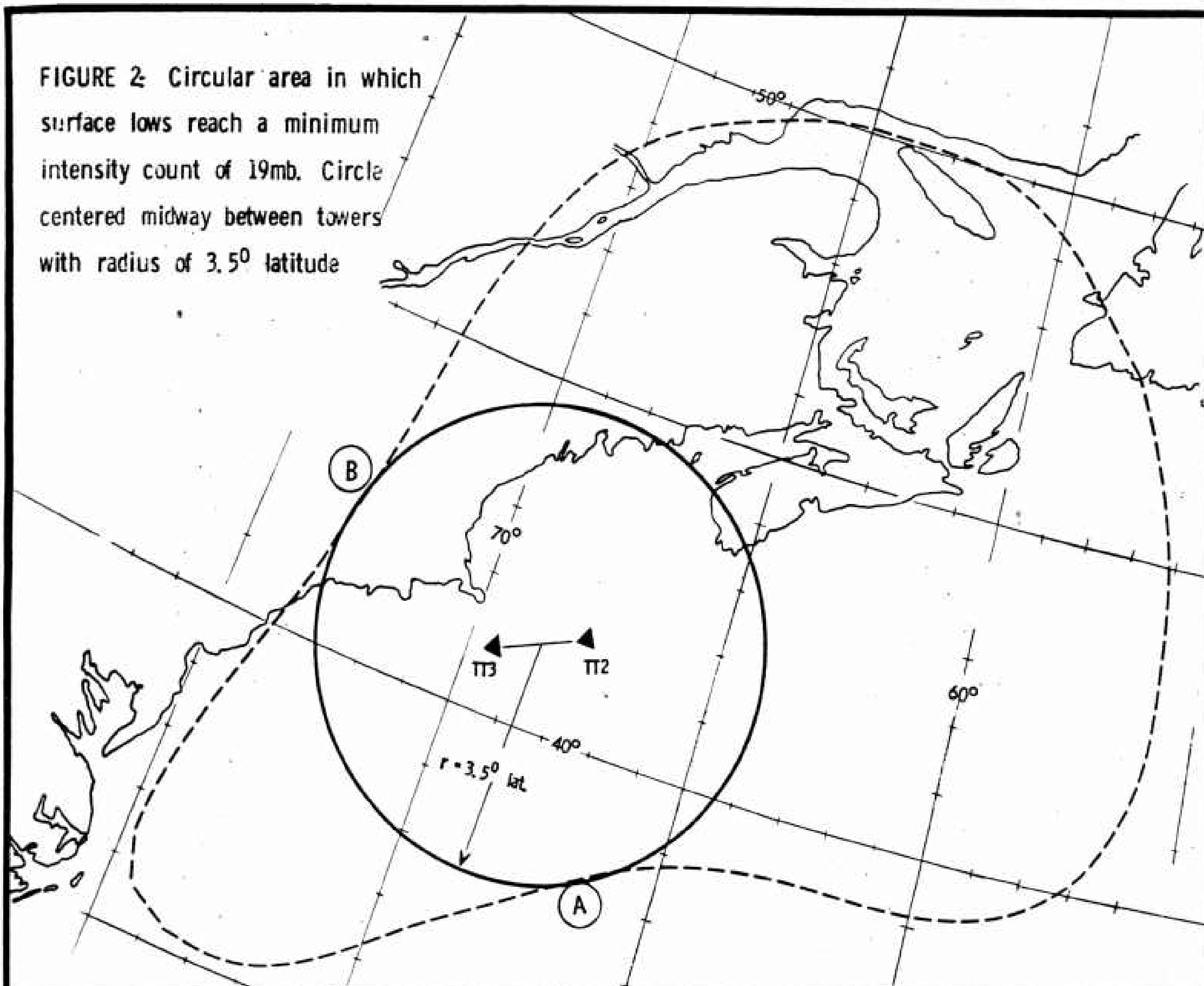


FIGURE 2. Circular area in which surface lows reach a minimum intensity count of 19mb. Circle centered midway between towers with radius of 3.5° latitude

the towers, regardless of the storm's intensity before it enters the tower area (Figure 1). Among all of the parameters investigated, this criterion proved to be the most significant in screening the 33 occurrence storms from the nonoccurrence storms which also traverse the tower area. The 1957-58 winter season is a good illustration of the screening ability. Forty storm systems moved through the circular area (within 210 nautical miles of the towers). Twelve of these storms produced sustained winds $\geq$50 knots at either tower, well over the climatological normal of eight storms per winter. During this abnormal season, all 12 Texas Tower storm occurrences met the 19 mb criterion while only 3 of the 28 nonoccurrence storms did. The negative check of all nonoccurrence storms in the entire five-year sample also yielded high verification scores. Section H contains the results of this particular test.

c. Wind speeds $\geq$50 knots may occur before the storm center enters the circular area, while it is in the area, or after it leaves the area. A comparison of Figure 1 with Figure 2 shows this distribution. The 50-knot winds occurred south of the circular area 24% (8/33) of the time; within the circular area 58% (19/33) of the time; and north of the circular area 18% (6/33) of the time. The number of cases in these areas are too few to permit definite conclusions or explanation, but it is interesting to note the following:

(1) Lows south of the circular area - (8 cases). Seven of these storms had intensity counts $\geq$16 mb upon entering the circular area and eventually reached intensity counts $\geq$27 mb as they moved through the circular area. Four of these storms (case 13, 21, 23, 24) eventually reached intensity counts $\geq$37 mb in the circular area. From

the time these storms entered the occurrence area to the time they entered the circular area, they experienced an average increase of intensity count of 8 mb. It appears that the rate and amount of development is important. Lows undergoing rapid cyclogenesis as they approach the circular area are likely to produce ≥50 knots at the towers before they enter that area.

(2) Lows north of the circular area - (6 cases). All of these storms maintained an intensity count ≥19 mb as they moved north of the circular area. About one-half of these storms regenerate north or east of the towers, reaching intensity counts as high as 36 mb. In each of the remaining half of the cases, a strong high pressure system to the west created a tight gradient over the tower area, and was at least as much a causative factor as the low pressure system.

d. One of the primary reasons for the difficulty in establishing a more specific timing relationship lies in the fact that the intensity count is a measure of the <u>average</u> pressure gradient over a large area around the storm center, and does not describe the nonlinear character of the pressure field. The 50-knot winds may occur in any quadrant and in restricted belts of the pressure system. In an effort to solve this problem, we explored parameters such as intensity counts for various radii, partial intensity counts in selected quadrants, pressure gradient from the low center toward the towers, and pressure gradient at the towers. We found no significant relationships. Although lacking a specific timing relationship, the intensity count criterion within the circular area still stands as a significant screening parameter for the primary problem, which is to identify those storms which produce sustained winds ≥50 knots.

4. <u>Storm Origin, Types and Tracks</u>.

a. <u>Origin and types</u>. Figure 3 shows the position of each storm at the time the low first appeared on the surface chart. Seventeen storms originated east of 85°W longitude while 21 storms originated west of 90°W longitude. The storms may be classified in five categories:

(1) Category I - (17 cases): This category includes all storms in which there was only one primary low pressure system, with a track from the United States interior. This category includes the following cases: 1, 2, 3, 6, 7, 9, 10, 12, 13, 15, 18, 22, 23, 26, 28, 29, 30.

(2) Category II - (4 cases): This category includes those storms which originated and developed off the east coast as a primary low, similar to the Type A low development described by Miller (13). This category includes the following cases: 32, 33, 37, 38.

(3) Category III - (7 cases): This category includes the secondary developments near and off the northeast coast of the United States, north of 36°N latitude. These secondary developments are normally associated with a primary low pressure system in the vicinity of Lake Erie or the St Lawrence Valley. The secondary low usually develops as the primary low either fills or moves slowly northeastward through the St Lawrence Valley. Miller (13) conducted a comprehensive investigation of this particular type of secondary development. These lows develop rapidly in an area of sparse oceanic data and pose the greatest forecast problems. This category includes the following cases: 5, 17, 27, 31, 34, 35, 36.

(4) Category IV - (5 cases): This category is similar to Category III except that this type of secondary development occurs

south of 36° north latitude near and off the southeastern coast of the United States. These secondary developments are usually associated with a primary low which moves northeastward on the western side of the Appalachian Mountains, filling or moving slowly as the secondary low develops. These secondaries may reach a stage as intense as the Category III type when they finally reach the tower area but they normally allow more time for predicting their development. This category includes the following cases: 4, 8, 19, 21, 24.

(5) Category V - (5 cases): This category includes those primary lows which normally approach the tower area from the west along or to the north of the 45th parallel (cases 14, 16, 20, 25). The actual tracks for these storms are shown in Figure 3. These lows are at least 500 nautical miles north of the towers at the time of the first winds $\geq$50 knots. A cold front normally extends southward from these lows and produces winds $\geq$50 knots with short durations. An exceptional case (case 11) is included in this category, even though the primary low traversed the storm occurrence area, because the high wind regime did not begin until this storm was more than 1000 nautical miles north of Texas Tower 3, and there is evidence that the 50-knot winds at Texas Tower 3 were caused by a frontal passage. Category V therefore contains the five cases of strong winds caused by cold frontal passages.

b. Storm tracks. Except for four of the FROPA cases (cases 14, 16, 20, 25), all storms track within a certain geographical zone before they enter the storm occurrence area. Figure 3 shows the northern and southern boundaries of this zone or "chute."

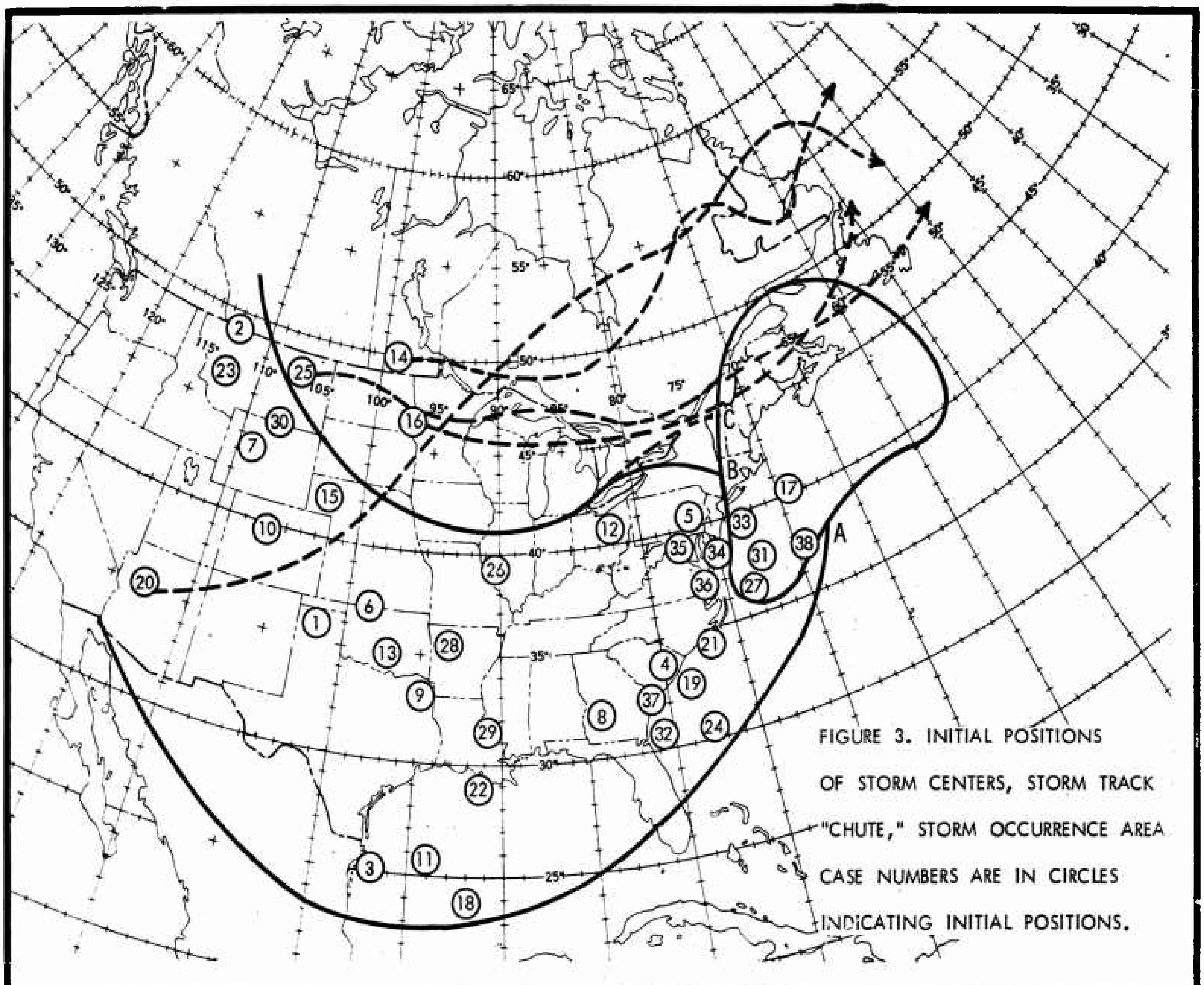
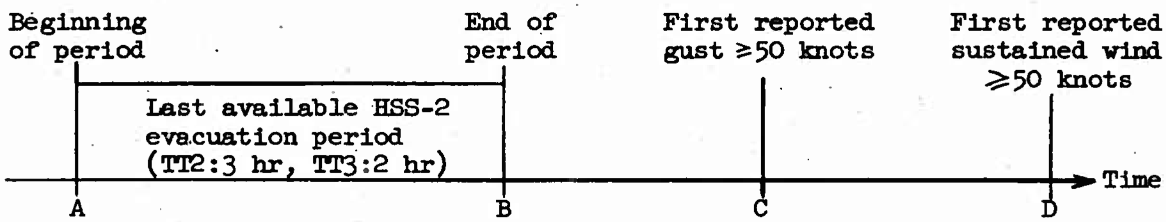


FIGURE 3. INITIAL POSITIONS OF STORM CENTERS, STORM TRACK "CHUTE," STORM OCCURRENCE AREA CASE NUMBERS ARE IN CIRCLES INDICATING INITIAL POSITIONS.

5. <u>Beginning Times of HSS-2 Evacuation Periods</u>.

a. Table 3 is a summary of the number of hours between the beginning of the last available HSS-2 evacuation period and the first reported gust ≥50 knots. The diagram below illustrates the time relationships:



AB represents the last period (three hours for Texas Tower 2 or two hours for Texas Tower 3) prior to the first gust ≥50 knots at the tower during which the ceiling, visibility, and wind speeds were favorable for HSS-2 evacuation. The summaries for individual towers in Table 3 refer to the period represented by AC. With the hour preceding time C not considered as part of the evacuation period, the minimum periods (AC) logged are four hours for Texas Tower 2 and three hours for Texas Tower 3. This is to assure, insofar as the hourly reports permit, the determination of a sufficient evacuation period.

b. As described earlier (Section B), evacuation begins at <u>both</u> towers on the basis of a forecast of sustained winds ≥50 knots at <u>either</u> tower. Since there is no distinction between towers, the third summary in Table 3 shows the number of hours between the earliest time A at either tower and the earliest time C at either tower. This provides

TABLE 3

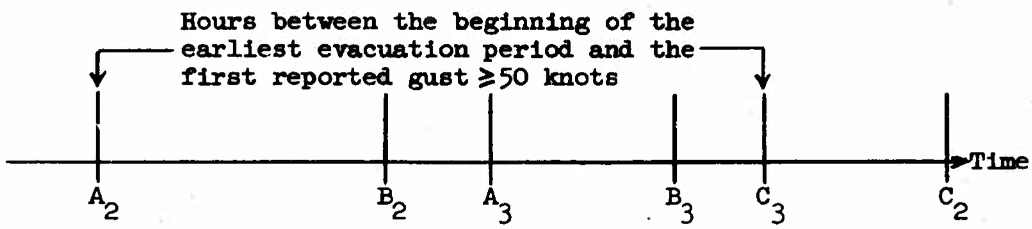
Times from Beginnings of Last Available HSS-2 Evacuation Periods and First Gusts ≥50 Knots

Case Number	Hours from beginning of HSS-2 evacuation period for three classes of ceiling/visibility limits to first reported gust ≥50 knots. (NA denotes data not available)						Hours from beginning of the earliest evacuation period to first reported gust ≥50 knots at either tower.		
	Texas Tower 2			Texas Tower 3					
	700'/1 mi	500'/1 mi	200'/½ mi	700'/1 mi	500'/1 mi	200'/½ mi	700'/1 mi	500'/1 mi	200'/½ mi
1	4	4	4	3	3	3	4	4	4
2	4	4	4	7	3	3	7	4	4
3	4	4	4	4	4	4	4	4	4
4	4	4	4	3	3	3	3	3	3
5	4	4	4	3	3	3	3	3	3
6	4	4	4	3	3	3	4	4	4
7	4	4	4	3	3	3	3	3	3
8	4	4	4	3	3	3	3	3	3
9	4	4	4	3	3	3	3	3	3
10	5	5	4	3	3	3	4	4	3
11	4	4	4	3	3	3	3	3	3
12	4	4	4	3	3	3	3	3	3
13	5	5	5	6	6	4	6	6	4
14	4	4	4	3	3	3	4	4	4
15	4	4	4	6	6	3	6	6	3
16	4	4	4	3	3	3	3	3	3
17	11	9	8	3	3	3	10	8	7
18	9	5	4	3	3	3	7	3	3

TABLE 3 CONTINUED:-

	Texas Tower 2			Texas Tower 3					
	700'/1 mi	500'/1 mi	200'/½ mi	700'/1 mi	500'/1 mi	200'/½ mi	700'/1 mi	500'/1 mi	200'/½ mi
19	4	4	4	8	8	7	8	8	7
20	4	4	4	3	3	3	3	3	3
21	5	5	4	5	5	4	6	6	4
22	4	4	4	6	3	3	5	4	4
23	4	4	4	6	6	3	6	6	3
24	4	4	4	5	4	3	4	4	4
25	4	4	4	NO	NO	NO	NO	NO	NO
26	4	4	4	NO	NO	NO	NO	NO	NO
27	4	4	4	NO	NO	NO	NO	NO	NO
28	10	6	6	NO	NO	NO	NO	NO	NO
29	4	4	4	NO	NO	NO	NO	NO	NO
30	4	4	4	3	3	3	4	4	4
31	5	5	4	5	5	3	5	5	3
32	4	4	4	3	3	3	3	3	3
33	4	4	4	7	3	3	7	3	3
34	11	9	4	3	3	3	11	9	4
35	5	4	4	4	3	3	4	3	3
36	5	4	4	3	3	3	5	4	4
37	4	4	4	3	3	3	4	4	4
38	9	4	4	9	3	3	9	4	4

a practical estimate of the necessary forecast lead time. The diagram below, where A, B, and C refer to the times labeled in the above diagram (with subscripts denoting the towers), illustrates the determination of this period:



In the example, time A_2 is the beginning of the earliest of the two last available evacuation periods. Henceforth we will simply call this time the beginning of the last available HSS-2 evacuation period.

c. The effect of applying three different classes of ceiling and visibility limits appears in Table 3. This study uses 700 feet and one mile, the normal limits for HSS-2 operations (1), as those determining suitable evacuation periods. The table gives interesting information about each tower's experience, but the third summary combining both towers' experience is that which is significant to the forecast problem. Of the 33 cases in this summary, 17 (52%) would have required the same lead time for all three sets of weather limits and 19 (58%) would have required no lead time beyond the three hours (covered by four hours in this table) required for evacuation. For 700'/1 mi we see that 19 (58%) of the cases would have required no extra lead time and that the longest period is 11 hours. Thus from this sample we have the climatological guarantee that if we could forecast the time of the first gust ≥50 knots accurately, then a successful evacuation will follow if begun 11 hours

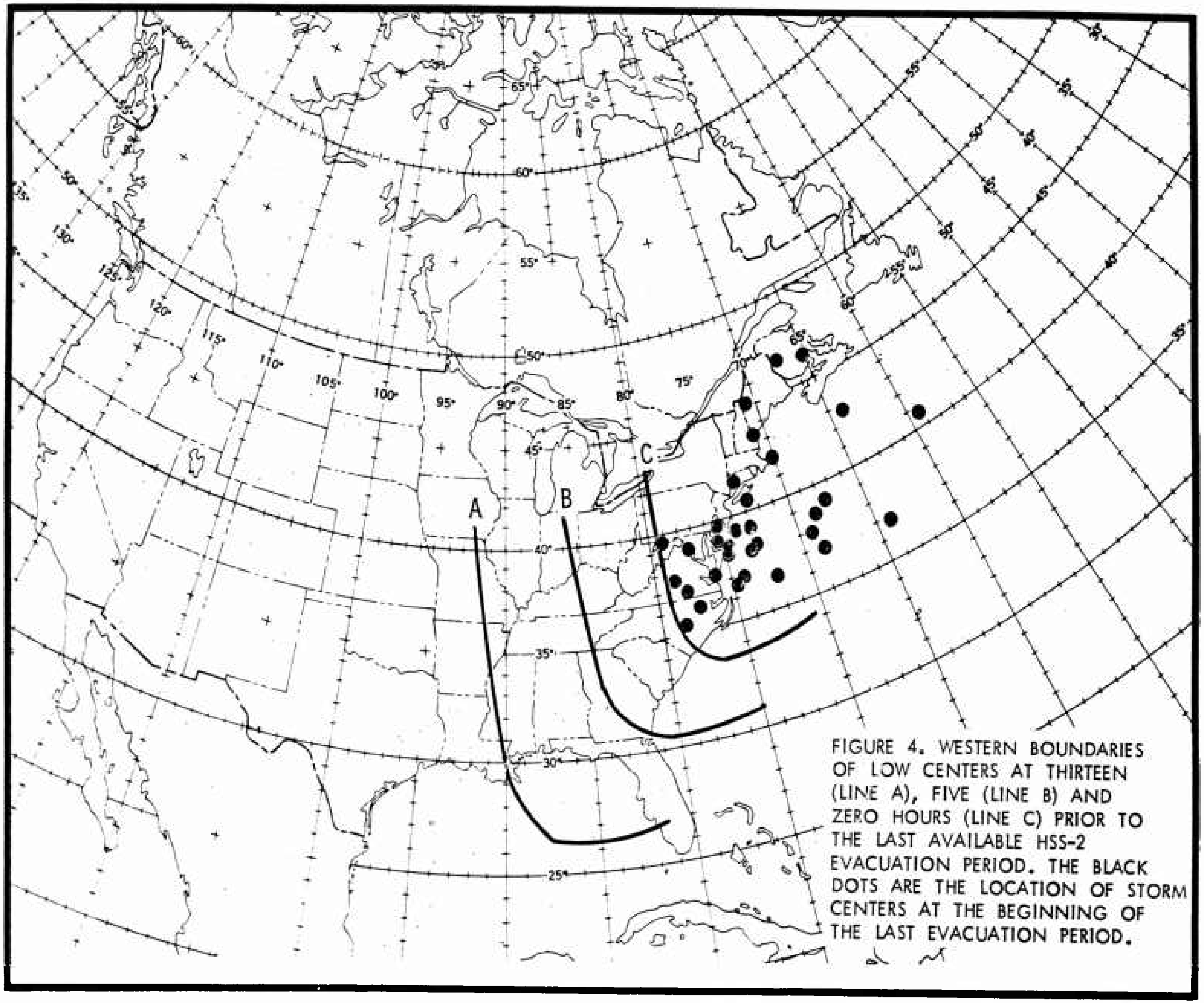


FIGURE 4. WESTERN BOUNDARIES OF LOW CENTERS AT THIRTEEN (LINE A), FIVE (LINE B) AND ZERO HOURS (LINE C) PRIOR TO THE LAST AVAILABLE HSS-2 EVACUATION PERIOD. THE BLACK DOTS ARE THE LOCATION OF STORM CENTERS AT THE BEGINNING OF THE LAST EVACUATION PERIOD.

before the first gust. This study has shown the futility of attempting to forecast the time of first gust. Rather than apply a climatological extreme to this aspect and then back up 11 hours, we chose another sort of climatological boundary concerned with the geographical positions of the storms.

6. Storm Locations at Beginning of HSS-2 Evacuation Periods.

a. Figure 4 shows the position of each low center at the beginning of the last available HSS-2 evacuation period. Line C is the western boundary of the various positions. In a similar fashion, Lines B and A resulted from plots of the low center positions at 5 and 13 hours before the beginning of the last available evacuation period.

b. Lines A, B, and C are climatological boundaries that a forecaster may use to evaluate each storm threat. He has a climatological guarantee that:

(1) When a storm center crosses Line A, at least 13 hours remain before the beginning of the last available HSS-2 evacuation period.

(2) When a storm center crosses Line B, at least 5 hours remain before the beginning of the last available HSS-2 evacuation period.

(3) An HSS-2 evacuation period remains at least until a storm center crosses Line C.

H. FORECAST PROCEDURE.

1. The features of Figure 5 consolidate the factors pertaining to the forecast procedure:

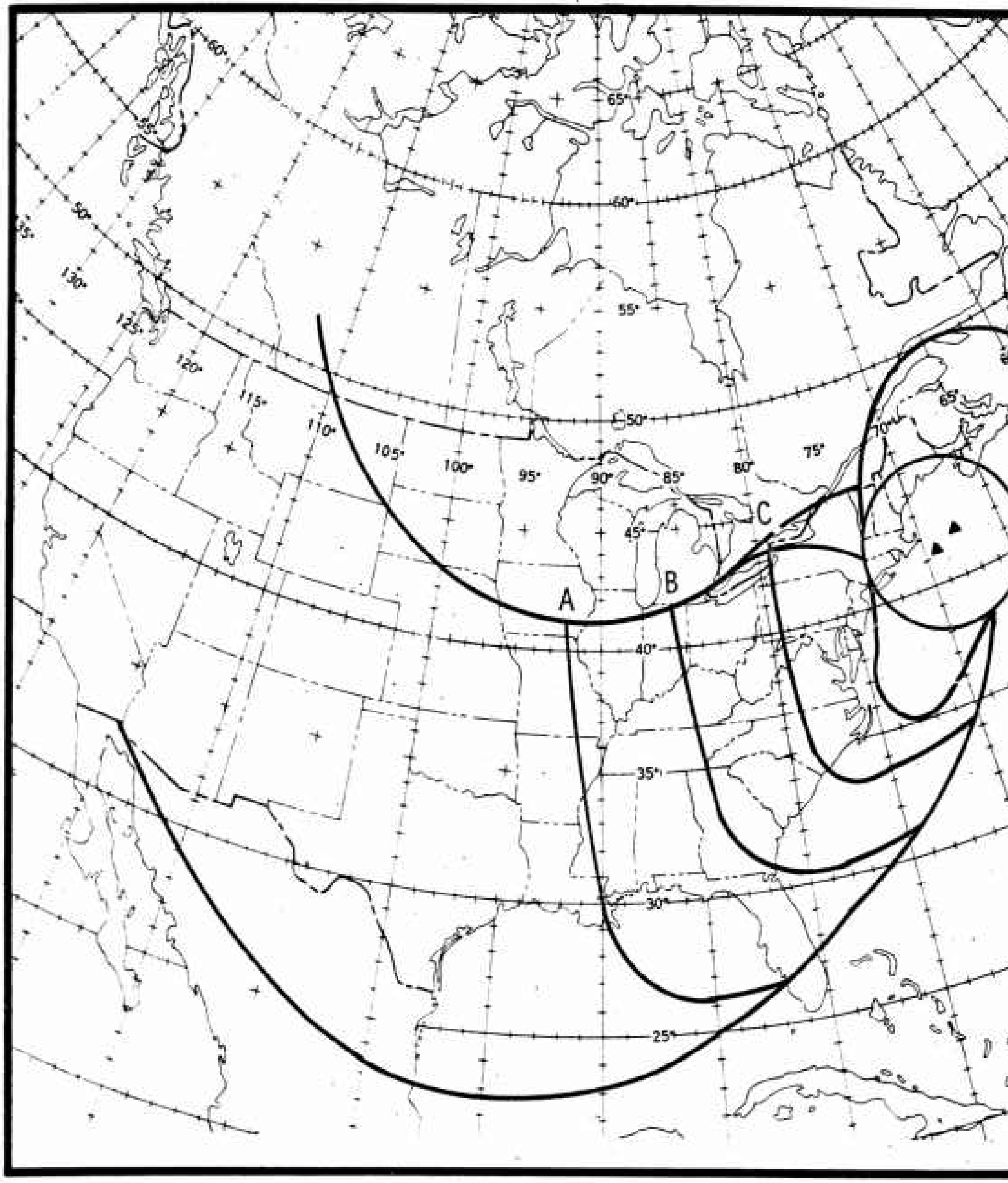


FIGURE 5. COMPOSITE FIGURE SHOWING THE "CHUTE," FORECAST DEAD LINES (A, B AND C), AREA OF STORM LOCATIONS AT THE BEGINNING TIME OF WINDS $\geq$ 50 KTS AND THE 3.5° CIRCLE ABOUT THE TOWERS AREA.

a. Where a storm center may be when sustained winds $\geq$50 knots occur at the towers (storm occurrence area).

b. The criteria for forecasting sustained winds $\geq$50 knots at the towers (circular area and "chute" boundaries).

c. The availability of a favorable HSS-2 evacuation period (Lines A, B and C).

2. The procedure for predicting the occurrence of sustained winds $\geq$50 knots at either of the towers is quite simple. With the use of National Meteorological Center analyses and prognostic charts as well as hourly data, the forecast procedure is as follows:

a. Consider that a storm threat exists when a low center exists or you expect one will exist in the "chute."

b. Forecast sustained winds $\geq$50 knots at the towers when you expect a low center will enter the storm occurrence area via the "chute" and reach an intensity count $\geq$19 mb while in the circular area.

3. As mentioned in paragraph C3, it is not simple to specify a forecast deadline. The lines A, B and C provide guidance to the forecaster as he appraises the various meteorological factors affecting the availability of a favorable evacuation period. If faced with a different set of operational factors than assumed in this study, he may have to use different weather and time limits in his appraisal, but he will probably still find it useful to know that:

a. As a low center crosses Line A, at least 13 hours remain before the beginning of the last available HSS-2 evacuation period.

b. As a center crosses Line B, at least five hours remain before the beginning of that last period.

c. There will still remain an HSS-2 evacuation period when a storm center crosses Line C.

I. <u>EVALUATION OF THE FORECAST PROCEDURE</u>.

1. Dependent data sample, 1956-1961.

a. We applied the procedure to every surface low which had a potential of affecting the towers during the five winter seasons, using the observed six-hourly synoptic weather maps as the "prognostic" charts. We evaluated the procedure to determine the extent to which the screening parameters (paragraph H2) discriminated between occurrence storms (≥ 50 knots) and nonoccurrence storms. During this period we found 225 surface lows were possible threats. Of these, 33 produced sustained wind speeds ≥ 50 knots and five lows were associated with cold fronts which also produced sustained winds ≥ 50 knots. The following contingency table shows the results from the dependent data sample. A "yes" forecast is a forecast of sustained winds ≥ 50 knots at either tower.

		Forecast		
		Yes	No	Total
	Yes	34	4	38
Observed	No	23	164	187
	Total	57	168	225

Overall % correct	88%	(198/225)
Skill score	0.65	
% of occurrences correctly forecast (prefigurance)	90%	(34/38)
% of nonoccurrences correctly forecast	88%	(164/187)
% of "YES" forecasts correctly verified (post agreement)	60%	(34/57)
% of "NO" forecasts correctly verified	98%	(164/168)

b. The four forecast errors (forecast NO-verified YES) were four of the five observed FROPA cases. One FROPA case (case 11 described in paragraph G4) would have been correctly forecast since the low associated with the cold front satisfied the "yes" criterion prior to the frontal passage. The scores above demonstrate the capability of the forecast procedure in screening occurrence storms from nonoccurrence storms, provided of course that perfect prognostic charts are available. Bearing in mind that the NMC surface prognostic maps are the predictive vehicle, this procedure will reflect any errors inherent in these prognostic charts. The true forecast scores may be lower. However, we have demonstrated that surface data criterion effectively screens occurrences from nonoccurrences.

2. Independent data sample, (October 1961-April 1962).

a. During this season, 4th Weather Wing forecasters used several subjective procedures due to changes in evacuation criteria and modes of evacuation. We did not complete the present investigation until after the 1961-62 season. However we used the 1961-62 winter season as an independent sample for testing the forecast procedure. To insure a rigid test of the procedure we based the forecast deadline on the time that storm systems crossed Line B (Figure 4) or a storm system

developed east of this line. We established this early forecast deadline to insure a rigid trial of the forecast method. The following summary shows the results from the independent data sample.

Number of observed storm occurrences $\geq$50 knots	11
Number of "YES" forecasts issued	12
% of storm occurrences correctly forecast (prefigurance)	64% (7/11)
% of "YES" forecasts correctly verified (post agreement)	58% (7/12)

b. Of the four forecast errors in the class, forecast NO-verified YES, two were caused by frontal passages, and two were caused by the incorrect NMC prognosis of Cape Hatteras secondary developments (see paragraph G4).

c. Of the five forecast errors in the class, forecast YES-verified NO, three were near misses in which the sustained winds verified between 45-50 knots. In the remaining cases, one storm produced 43 knots and the other 36 knots.

J. DISCUSSION.

1. Two of the scores in Section I are the prefigurance and post agreement scores (14).

a. The prefigurance score (percentage of occurrences correctly forecast) is a measure of the forecaster's capability in providing an accurate advance notice or alert of a storm occurrence. Safety of tower personnel is the prime consideration (1), therefore the customer desires high "prefigurance" or "capability" percentages. When this score is high, the customer will have a high degree of assurance that a storm which may cause personnel or materiel losses will be correctly predicted

in advance.

b. The post agreement (percentage of YES forecasts correctly verified) score is a measure of the reliance to be placed on a forecast of the storm occurrence. From operational considerations, the customer desires high "post agreement" or "reliability" percentages in order to keep unnecessary precautionary measures to a minimum. A low score means that the customer performed a large number of unnecessary evacuations which reduced his operational capability.

c. When forecasting rare events such as Texas Tower storm occurrences, high scores of both types are rarely achieved. One of the scores is usually high at the expense of the other (15). The customer must decide whether the safety aspect is more important or less important than the operational aspect. This decision is based upon the ratio of the cost of taking precautionary measures to the penalty caused by operating under the hazardous condition. Concerning the Texas Tower problem, the customer has specified that this ratio is very low. Safety is the primary and most important consideration (1) and no more than seven people should be aboard the towers during sustained winds of ≥ 50 knots. Therefore, concerning Texas Tower wind forecasts, the customer desires prefigurance or capability scores as high as possible. This qualification, heretofore unspecified, is therefore a very important fact to consider when evaluating the results of the forecast procedure.

2. The prefigurance or capability score for the dependent sample containing five winter seasons was 90% (34/38) at the expense of a 60% (34/57) post agreement or reliability score. Excluding the four cases of frontal winds, the prefigurance score would increase to 100% (34/34).

This of course depends upon a perfect prognostic map system. During the 1961-62 independent data season, the prefigurance score was 64% (7/11), because of inaccuracies in the prognostic charts, at the expense of a 58% (7/12) post agreement score. Excluding the two cases of frontal winds, the prefigurance score would increase to 78% (7/12).

a. The post agreement scores in both sets of data appear comparable and stable. It is reasonable to assume that 60% represents a good estimate of future reliability, i.e., a tendency to over-forecast exists and about 40% of storm occurrence forecasts will not verify.

b. The prefigurance score of 64% is considerably lower in the 1961-62 test, but we do not believe that it is a good estimate of future capability. We hope that this study will provide the forecaster with:

(1) Increased capability to forecast winds ≥ 50 knots at the towers.

(2) A better understanding of the forecast problem.

(3) Stimulation for further research to improve the forecast procedure.

K. SUGGESTIONS FOR FUTURE RESEARCH.

1. During the five years used for developing the forecast study, five frontal passages produced winds of ≥ 50 knots at the towers. A total of 90 frontal passages occurred during the five year period of record. Based upon hourly data, the probability of getting winds ≥ 50 knots at the towers with a frontal passage is 5.6%. However, since these hourly observations will miss short duration winds of ≥ 50 knots, a more realistic probability is about 10%. High wind speeds of short duration are seldom associated with high seas, since it takes time (and fetch) to

build up the high seas which, combined with strong winds, are a real hazard to the towers. This study has not covered the problem of forecasting frontal winds, so if required in the future, forecasting winds of ≥ 50 knots associated with frontal systems will involve further investigation.

2. As stated in Section C, most of the wind speeds used in this study are from regular hourly observations, since special observations rarely appeared on the tower WBANs. Therefore a small sample of the total wind experience has determined the beginning and ending times of significant wind speeds. Since the installation of wind recording equipment on the towers in the summer of 1961, a continuous record of the winds has been available. In a few years, when enough of these data are available to merit investigation, revisions to this study will be in order.

3. The forecaster uses the NMC prognostic charts as a first approximation to predict a storm's track and intensity count in the circular area. He then uses later data to appraise the NMC products, his primary sources being hourly surface reports and six-hourly winds aloft data. With these data he follows the storm's track and development and watches for secondary lows. Modification of facsimile products is discussed in AWS Manual 105-35 and AWS Manual 105-55. A worthwhile area for further research is the development of procedures for modifying NMC charts as needed in the specific problem of forecasting strong winds at the Texas Towers. Of particular concern is the appraisal of aging prognostic charts when time is running out (storm center nearing Line C) in a doubtful situation and when an unexpected low develops close to or even within

the storm occurrence area. Here it is possible that surface data from coastal stations near the occurrence area are the key.

4. Secondary lows and new primary lows that develop off the East Coast present the greatest problem in applying the forecast procedure. Special study on the forecasting of these developments offers the most potential aid to the forecaster and ties in with paragraph 3 above. Miller's study (13) is particularly applicable to this problem.

5. As discussed in paragraph G5c, the forecaster could use the climatological fact that 11 hours' notice of impending wind speeds of ≥50 knots at the towers would always allow an HSS-2 evacuation. To use this, he must be able to forecast the time of the first gust of ≥50 knots rather accurately. Research on the problem of timing the first gust of ≥50 knots would, if productive, pay off in forecast accuracy and reduced loss of operational time at the towers.

6. Although the primary forecast problem is to identify storms which produce sustained winds ≥50 knots, the 70-knot criterion (1, p 7) poses a secondary forecast problem. The seven personnel remaining on the towers after the completion of Phase IIb are evacuated after the winds <u>actually</u> reach 50 knots (gusts) and the storm is predicted to continue its intensification and produce sustained winds ≥70 knots. There were only two cases of reported sustained winds ≥70 knots (cases 21 and 24) during the five winter seasons, too few to permit definite conclusions. In order to conduct further investigation of the secondary forecast problem, we suggest that the sample of data be increased by including six additional storms which produce <u>gusts</u> ≥70 knots (cases 2, 3, 10, 19, 23, 26). Common characteristics of these storms should be determined and tested as screening parameters.

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